



Economic Perspective of Trends and Determinants of Paddy Stubble Burning in North Western India

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HIGHLIGHTS

- The study focused on analyzing the spatio-temporal trends of paddy stubble burning events and area in North Western India.
- State-wise analysis figures out the districts that need attention to reduce the practice of burning.
- Panel regression provides an alternative way to curb this practice.

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ABSTRACT

During the paddy harvesting season in North-Western India, a significant smog problem occurs due to the unhealthy practice of stubble burning, which also reduces soil fertility. The government has implemented various efforts to lessen its severity. By using tabular analysis of burning events, this study found that the number of such events decreased from 2016 to 2021 in North-Western India. The Mann-Kendall test indicated a negative trend in burning events for the three states of Punjab, Haryana, and WUP. In Punjab, about 49% of the paddy area is burned, with the growth rates of the burnt area and paddy area being nearly equal. Conversely, in Haryana, only 17% of the paddy area is burned, but its burnt area is growing at a faster rate than the paddy area itself. Districts like Firozpur, Faridkot, Patiala, and Sangrur in Punjab, along with Fatehabad, Kurukshetra, and Karnal in Haryana, require special attention due to their relatively high percentage of paddy area subjected to burning. Panel regression analysis suggests that cultivating potato and basmati rice can reduce the paddy area affected by burning.

INTRODUCTION

The burning of crop residue in open field has become a significant concern for climate change mitigation efforts worldwide (Raza et al., 2022). Although crop residue burning is a common practice in many Asian countries such as Brazil, Indonesia, Thailand, and China, this issue in India needs special attention (Kaushal & Prashar, 2021). India, being the second largest agro-based economy with year-round crop cultivation, generates a surplus crop residue of about 141 million tons a year, out of which 92 mt is subjected to burning. Haryana, Punjab are one of the most widely studied contributors of paddy residue burning (CRB) in

northern India. Uncontrolled CRB is a major source of air pollution that affects human health, global climate change, and atmospheric chemistry (both local and regional) (Hiloidhari et al., 2019; Mehmood et al., 2018). In Punjab about 95 per cent of the 22.9 metric tonnes of paddy straw is burnt on the field (Bimbraw, 2019). The episodic CRB in the States of Punjab, Haryana and Uttar Pradesh during post-monsoon has altered the air quality of Delhi and Kanpur for the worse (Nagar et al., 2019).

The WHO has set a standard for permissible levels of PM_{2.5} in the air is which is 5 µg/m³ whereas according to India's National Ambient Air Quality Standard (NAAQS) the permissible level for PM_{2.5} is 40 µg/m³ (Bhuvaneshwari et al., 2019). Study of Saxena et

al. (2021) has shown that in 2021, PM_{10} and $PM_{2.5}$ concentrations exceeded NAAQS limits by 2–3 times, while NO_2 and SO_2 stayed within the limits in post post-burning period in Delhi. They used MODIS fire observations to estimate CRB fire counts, and found that rabi fires in Haryana are ~3 times higher and more intense than in kharif. Furthermore, backward trajectories show air mass movement from Haryana, Punjab and Pakistan (Saxena et al., 2021). Between 2003 to 2019, agricultural residue burning caused 44,000–98,000 particulate matter exposure-related premature deaths annually, of which Punjab, Haryana, and Uttar Pradesh contribute 67–90 per cent. Due to a combination of relatively high downwind population density, agricultural output, and cultivation of residue-intensive crops, six districts in Punjab alone contribute to 40 per cent of India-wide annual air quality impacts from residue burning (Lan et al., 2022).

Having all these impacts, the study of burning scenarios of North Western India (NWI) becomes a matter of importance, which will serve to take curative measures to reduce this practice. So, this study makes a thorough analysis of burning events and burning area of paddy for each district of Punjab, Haryana and Western Uttar Pradesh (WUP), by applying various methodologies. It also assesses the factors influencing the practice of burning by the Panel regression technique.

METHODOLOGY

The secondary data used in the study includes the district-wise weekly number of paddy stubble burning events, for nine weeks (1st October to 31st November) that occurred in Punjab, Haryana and WUP for the past six years (2016 to 2021). Further, based on availability, we also used paddy stubble burnt area in only Punjab and Haryana states for four years (2018 to 2021). The secondary data for both analyses is collected from the CREAMS (The Consortium for Research on Agro Ecosystem Monitoring and Modeling from Space) website, handled by the Division of Agricultural Physics, ICAR-IARI. The CREAMS lab uses the thermal data to monitor in real-time, the active fire events for paddy and wheat in north India, and they have used a high spatial resolution multispectral image of pre and post-burning periods for mapping and estimating burnt area reliably (Sehgal et al., 2021; Jambagi et al., 2023). And the other related data, like area under paddy, wheat, potato, groundwater irrigated area, and cropping intensity, are taken from the Directorate of Economics and Statistics; the area under basmati paddy is taken from the “Basmati Crop Survey Report” of APEDA. Weekly data on the number of paddy stubble burning events that occurred in Punjab, Haryana, and WUP over the past six years were subjected to preliminary tabular

analysis to identify the spatial and temporal pattern of burning events in NWI.

The direction and magnitude of trends in burning incidents for each district in the aforementioned states were examined in this study using two non-parametric techniques: Mann-Kendall and Sen’s slope estimator, as these techniques require that the data be independent regardless of distribution pattern (Athare et al., 2023).

Identifying stubble burning drivers is vital for communicating the effective policy. Data on the area subject to stubble burning from 2018 to 2021 was used to identify covariates influencing the proportion of area under paddy burning. The following model was used to estimate effect on paddy burnt area,

$$\text{Burnt area}_{i,t} = b_0 + b_1 X_{1,t} + b_2 X_{2,t} + \dots + X_n + e_{i,t}$$

Where, $X_1 - X_n$ = Area under potato, Area under basmati paddy, Area under paddy, Area under wheat, cropping intensity, rural male literacy, groundwater irrigated area. i, t = cross-sectional, time series component, e = error term

RESULTS

The spatio-temporal distribution of paddy straw burning events in NWI

The spatial distribution of paddy straw burning events in NWI for the period 2016 to 2021 is shown in Table 1, which reveals that the average number of events over the last six years is 87636.8 per year, among which 84 per cent of the events have occurred in Punjab, 11.6 per cent in Haryana and 4.2 per cent in Western UP. But, when we consider the area under paddy cultivation in the study region it was found that Punjab’s contribution decreased to 71 per cent, whereas Haryana and Western UP’s contribution increased to 22.6 and 6.6 per cent, respectively.

The trend of farm fire events in NWI for the period 2016 to 2021 is shown in Figure 1. Among the 5,24,826 number of farm fire events, a maximum of 23.6 per cent of the events have occurred in 2016 followed by a declining trend till 2019. The same has been reported on CREAMS portal, which stated that about 15 and 41 per cent reduction in number of burning events were observed in 2018, then that of 2017 and 2016 respectively. This decline can be attributed to the various efforts and measures taken by the government such as the ban on stubble burning implemented in 2015, the measure to give compensation of rupees 1500/acre for the farmers who has not burnt the paddy, and the scheme “Promotion of Agricultural Mechanization for In-Situ Management of Crop Residue in the States of Punjab, Haryana, Uttar Pradesh and NCT of Delhi” implemented in 2018. However, again the number of events got raised in later years. This increase of fire events was

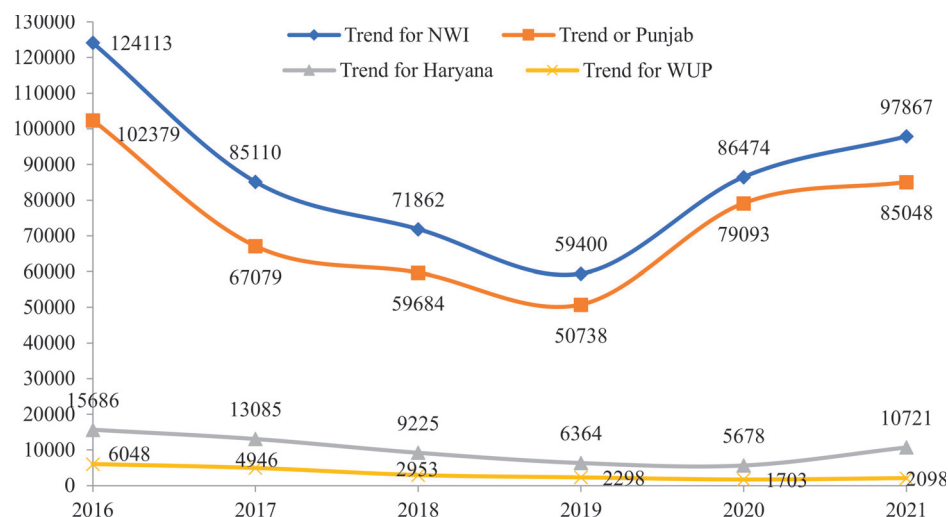
Table 1. The spatial distribution of paddy straw burning events in NWI

States	Average paddy area		Average burning events		Events/lakh ha of paddy area	
	Lakh ha	Share (%)	No./year	Share (%)	No.	Share (%)
Punjab	31.3	51.7	74003.5	84.4	2364	70.8
Haryana	13.4	22.1	10126.5	11.6	756	22.6
WUP	15.85	26.2	3506.8	4.2	221	6.6
Total	60.55	100.0	87636.8	100.0	3341	100.0

Source: Directorate of Economics and Statistics and <http://creams.iari.res.in>

Figure 1. The Temporal distribution of paddy straw burning events in NWI

Source: <http://creams.iari.res.in>



mainly contributed by the state Punjab in the year 2020 and Haryana in 2021. The reason for increase in the number of events from Punjab in 2020 can be partially attributed to the protest of farmers against new farm laws (Sharma, 2022) and the inaction of officials at the time.

A weekly analysis of the events has shown that around 70 per cent of the events occur in the fourth, fifth, and sixth weeks (22nd October to 11th November) of the study period (1st October to 30th November), which corresponds to the wheat sowing period. Among these, the sixth week, from 5th to 11th November, contributed 29 per cent, followed by the 5th and 4th weeks. Whereas, the initial weeks of October and the last weeks of November have a meager number of events.

District-wise trend and growth rate of burning events

As evident from Table 2, the negative sign of Kendall's tau statistics indicates that farm fire events have a decreasing trend in the state of Punjab in the study period, with an annual rate of decrement of 3466.20. And almost all the districts exhibited the negative trend except districts like Bathinda, Amritsar, Fazilka, Muktsar, and Kapurthala; however, most are non-significant.

The compound annual growth rate (CAGR) of area under paddy and area of paddy subjected to burning in the period 2018 to 2021, has been calculated for the state Punjab and given in the Table 5 and it has been found that burnt area has been grown at a rate of 1 % in the state, whereas the paddy area has been grown at

Table 2. Estimates of Mann-Kendall test, Sens slope and CAGR for Punjab

Districts	z value	Kendall's tau	Sens slope	p value	CAGR of paddy area (%)	CAGR of burnt area (%)	Share of burnt area in paddy area (%)
Amritsar	0.75	0.33	31.00	0.45	0.7	25	31.27
Barnala	0.00	-0.07	-151.00	0.01	0.5	4	54.73
Bathinda	0.00	0.07	535.00	0.09	2.6	-8	53.31
Faridkot	0.00	-0.07	-78.20	0.06	0.3	-9	67.02
Fatehgarh Sahib	-0.38	-0.20	-100.67	0.03	0.2	16	54.71
Fazilka	0.00	0.07	36.00	1.00	1.6	-5	47.75
Firozepur	0.00	0.07	-12.00	0.02	0.5	-9	66.59
Gurdaspur	-0.38	-0.20	-60.50	0.01	-0.1	8	34.26
Hoshiarpur	0.75	-0.33	-23.00	0.05	1.5	66	25.23
Jalandhar	0.00	-0.07	-79.33	0.07	0.6	-2	47.47
Kapurthala	0.00	0.07	11.00	0.08	-0.1	-11	49.42
Ludhiana	-0.38	-0.20	-680.60	0.01	0.1	6	47.23
Mansa	0.00	-0.07	-73.00	0.02	3.2	-6	51.32
Moga	0.00	-0.07	-56.00	0.03	0.3	6	54.75
Muktsar	0.00	0.07	19.00	0.09	1.7	-16	54.42
Pathankot	0.81	0.75	0.00	0.06	0.4	-5	21.08
Patiala	0.00	-0.07	-154.80	0.04	0.1	375	61.75
Rupnagar	0.00	-0.07	-42.67	0.02	0.3	-28	36.02
S.A.S Nagar	0.38	0.20	-365.00	0.01	-2.9	-39	41.64
Sangrur	-0.38	0.20	2.00	0.00	0.6	134	65.32
S.B.S Nagar	-1.50	-0.60	-184.00	0.13	0.7	99	25.05
Tarn Taran	0.00	0.07	4.00	1.00	0.5	-3	51.53
Total	0.00	-0.07	-3466.20	0.02	0.7	1	49.10

Source: <http://creams.iari.res.in>

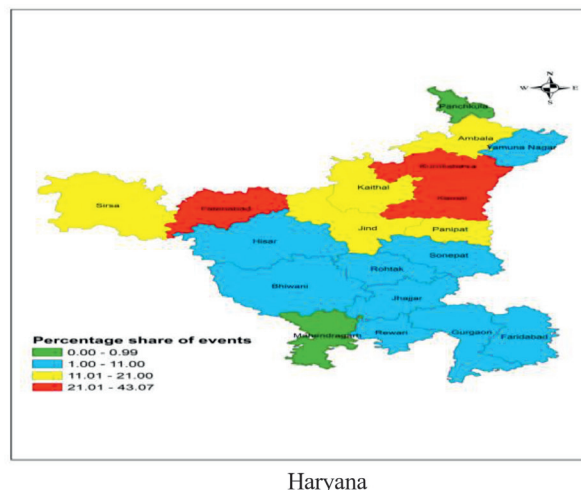
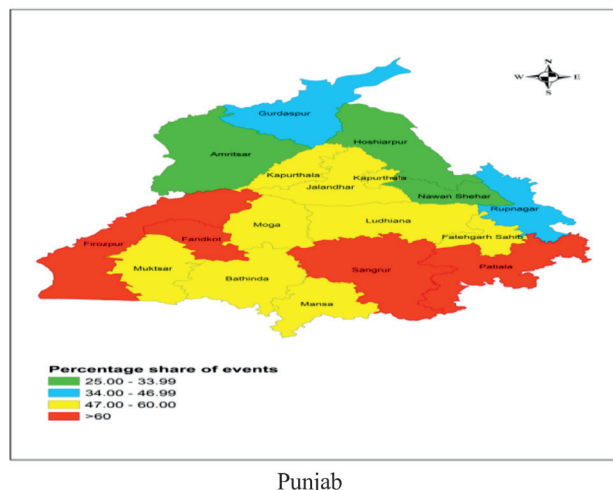
Table 3. Estimates of Mann-Kendall test, Sens slope and CAGR for Haryana

Districts	z value	Kendall's tau	Sens slope	p value	CAGR of paddy area (%)	CAGR of burnt area (%)	Share of burnt area in paddy area (%)
Ambala	-0.38	-0.20	-11.0	0.03	3.1	40	11.15
Bhiwani	-1.13	-0.47	-11.0	0.02	0.7	-49.6	5.82
Charkhidadri	1.62	0.73	1.0	0.01	-13.3	0	0.04
Faridabad	-1.88	-0.73	-71.3	0.06	5.4	-24	2.05
Fatehabad	-1.50	-0.60	-833.3	0.03	1.7	-2.7	43.07
Gurgaon	1.75	0.77	1.0	0.08	1	-15.16	6.02
Hisar	0.00	-0.07	-12.3	1.00	4.3	-20.5	10.64
Jhajjar	-0.75	-0.33	-4.4	0.45	1.2	-53.3	2.32
Jind	0.00	0.07	13.5	0.01	0.7	6	17.34
Kaithal	-1.50	-0.60	-163.3	0.13	1.4	9.1	20.99
Karnal	-1.13	-0.47	-138.0	0.26	0.5	28.3	24.07
Kurukshetra	-1.50	-0.60	-113.3	0.13	0	22.1	26.89
Mewat	0.45	0.26	0.0	0.65	-7.9	0	3.92
Palwal	1.41	0.60	29.0	0.02	2.1	-0.2	10.84
Panchkula	2.10	0.83	6.5	0.04	7.1	-19.48	0.80
Panipat	0.00	0.07	4.0	0.09	2.4	205.9	13.61
Rewari	0.45	0.26	0.0	0.65	-4.9	-67.39	7.52
Rohtak	0.00	-0.07	2.0	0.09	8.5	24.9	2.95
Sirsa	-1.50	-0.60	-626.0	0.00	1.2	-20.1	19.38
Sonipat	0.38	0.20	11.0	0.01	1.5	56.8	8.02
Yamunanagar	0.00	-0.07	1.3	1.00	3.9	36.9	10.00
Total	-1.50	-0.60	-2469.0	0.03	1.8	9.6	17.69

Source: <http://creams.iari.res.in>

rate of 0.7%. In some districts like Patiala, Sangrur, S.B.S Nagar, Hoshiarpur, and Amritsar, the growth rate of burnt area is comparatively higher than the growth rate of paddy area, which is a matter of serious concern. When the percentage of burnt paddy area in total paddy area is considered, the districts can be divided into four zones based on the mean (47) and standard deviation (13) values of percent burnt area. Accordingly, districts like Firozepur, Faridkot, Patiala, and Sangrur fall in the red region as the percentage of paddy area burnt in these districts is more than 60%. The districts like Barnala, Bathinda, Fatehgarh Sahib fall in yellow region (47 to 60%). Gurdaspur, Rupnagar, S.A.S Nagar in blue (34 to 47%) and districts like Amritsar, Hoshiarpur, and S.B.S Nagar (Nawan Shehar) fall in green region (< 34 %) (Figure 2).

As evident from Table 3, the negative sign of Kendall's tau statistics indicates that farm fire events have a decreasing trend in Haryana in a study period, with an annual rate of decrement of 2469. Districts like Fatehabad (-833.3) and Sirsa (-626) are exhibiting a significant annual rate of decrement. But some districts like Palwal, Jind, Panchkula, Sonipat, and Panipat need a special attention since they are exhibiting positive or increasing trend of burning events. The CAGR for the state of Haryana shows that the burnt area in the state has grown at a rate of 9.6%, which is higher than the paddy growth rate of 1.8%. And, also in districts like Panipat, Sonipat, Karnal, Kurukshetra, Kaithal, Jind, and Ambala, the growth rate of burnt area is comparatively higher than paddy growth rate, which calls for the need of special attention.

**Figure 2.** Classification of districts based on the percentage of paddy area burnt

Source: Author's calculation

The same analysis for Haryana, classifies the districts based on mean (11) and standard deviation (10). The districts like Fatehabad, Kurukshetra and Karnal falls in red region (>21%), Jind, Sirsa, Kaithal etc in yellow (11 to 21%), Hissar, Yamuna Nagar etc in blue region (1 to 11%) and Panchkula district falls in green region for having a less than one percent of burnt area in total paddy area (Figure 2).

Based on the availability of data, only trend analysis of burning events for WUP has been analyzed and is represented in Table 4, which reveals that there is a negative trend of fire events in the study period, with an annual decrement of about 7966. Almost all districts have a decreasing trend except districts like Amroha (5.50), Badaun (2.33) and Baghpat (6.25), which exhibited a significant increasing trend and call for a preventive measure.

Factors influencing the practice of burning

A fixed effects panel data regression model was employed to investigate the factors influencing the extent of stubble burning in the targeted region. Initially, both random effects and fixed effects models were applied. However, based on the Hausman test results ($\chi^2(7) = -533.07$, Probability < $\chi^2 = 0.00$), the fixed effects model was determined to be more appropriate for the analysis. To account for potential panel effects, a BP-LM test was conducted ($\chi^2(253) = 506.0$, Probability > $\chi^2 = 0.00$). The results of this test indicated the presence of significant panel-specific effects, which

further supported the choice of a panel data regression model over a pooled regression model. To address the issue of heteroscedasticity, as it can compromise the efficiency of ordinary least squares estimates and invalidate tests of statistical significance, the error terms of the panel data regression were subjected to a Wald test for group-wise heteroscedasticity ($\chi^2(36) = 4189.71$, Probability > $\chi^2 = 0.00$). In addition, an alternative approach was considered by utilizing the Generalized Least Squares (GLS) model to obtain efficient standard errors. Specifically, a two-way fixed effects model was employed, incorporating district dummies and time dummies. This approach allowed control for both time-invariant location-specific factors and time-varying factors that were uniform across different sections of the dataset. The analysis combined the data from both Punjab and Haryana, providing a comprehensive assessment of the factors contributing to stubble burning in this region.

The model's goodness of fit was assessed using R-squared (R^2) and the F-statistic, and the overall model was found to be suitable for interpreting the results. Based on the results presented in Table 5, it was observed that as the area under potato cultivation increased, there was a corresponding decrease in the area affected by stubble burning. This finding aligned with the null hypothesis, suggesting that an increase in the area under vegetable crops reduced burning. The production of basmati rice was also found to be inversely related to the area of burning. This relationship could be partially attributed to the market potential of basmati paddy straw, which is usually harvested manually. Conversely, a higher rural male literacy rate was associated with an increase in the area of burning. This indicated that awareness and adoption of improved agricultural practices were not effectively communicated in this context. As literacy rates increased, individuals sought to capitalize on the economic benefits of the paddy-wheat cropping system by reducing the turnaround time through stubble burning. Furthermore, an

Table 4. Estimates of Mann-Kendall test and Sens slope for WUP

21	z value	tau	Sens slope	p value
Agra	1.81	0.75	1.75	0.07
Aligarh	0.38	0.20	-1.0	0.01
Amroha	2.21	0.89	5.50	0.03
Badaun	1.41	0.60	2.33	0.04
Baghpat	2.21	0.89	6.25	0.03
Bareilly	-2.63	-1.00	-45.50	0.01
Bijnor	0.00	-0.07	-8.00	1.00
Bulandsagar	0.75	0.33	1.40	0.45
Ethah	-0.75	-0.33	-3.00	0.05
Firozabad	-0.19	-1.38	-0.25	0.04
Gautambudhnagar	-0.75	-0.33	-4.00	0.04
Muzafarnagarshamli	-0.38	-0.20	-17.20	0.01
Ghaziabadhapur	-1.50	-0.60	-12.80	0.03
Hathras	0.00	0.12	0.00	0.00
Kannauj	-0.96	-0.41	-3.00	0.03
Kasganj	0.45	0.26	0.00	0.05
Mainpuri	-1.34	-0.55	-10.33	0.08
Mathura	-2.25	-0.87	-309.50	0.02
Meerut	-0.75	-0.33	-13.00	0.04
Moradabad	-0.75	-0.33	-4.67	0.03
Pilibhit	-2.25	-0.87	-200.50	0.02
Rampur	-1.50	-0.60	-107.00	0.01
Ambhal	0.90	0.43	0.00	0.03
Shahjahanpur	-1.50	-0.60	-172.00	0.01
Sharanpur	-0.38	-0.20	-12.75	0.07
Auraiya	-1.13	-0.47	-40.60	0.02
Etawah	-0.75	-0.33	-18.00	0.04
Farrukhabad	1.49	0.60	1.00	0.16
Total	-2.25	-0.87	-796.00	0.02

Source: <http://creams.iari.res.in>

Table 5. Two-Way Fixed Effect Panel Regression

Variables	Coefficient	Standard Error
Area under potato (ha)	-0.018***	0.006
Area under basmati (000 ha)	-1.785**	1.001
Area under paddy (000 ha)	0.356***	0.848
Area under wheat (000 ha)	0.006*	0.003
Cropping intensity (%)	0.169	0.206
Rural male literacy (%)	1.300***	0.385
Groundwater irrigated area (000 ha)	0.0148***	0.003
Constant	-2806.31	1785.8
Diagnostic Statistics	sigma_u	6494.2
	sigma_e	35.53
	rho	1.00 F (36, 89)
		Prob > F = 0.0000
R ² Within = 0.665	Sample size	133
R ² Between = 0.979	No. of groups	37
R ² Overall = 0.952		

Wald $\chi^2(36) = 4189.71$, (Probability > $\chi^2 = 0.00$), Hausman test $\chi^2(7) = -533.07$, (Probability < $\chi^2 = 0.00$), BP-LM test $\chi^2(253) = 506.00$, (Probability > $\chi^2 = 0.00$)

***Coefficient statistically significant at 1%, **Coefficient statistically significant at 5%, *Coefficient statistically significant at 10%

increase in the area under groundwater irrigation was associated with an increase in burning, thereby rejecting the null hypothesis (Jatav, 2024; Kumar et al., 2022). Field visits supported this finding, as access to groundwater irrigation enabled farmers to shorten the interval between paddy and wheat cultivation, which in turn led to a greater reliance on stubble burning.

DISCUSSION

Analysis of paddy stubble burning incidents across Punjab, Haryana, and Western Uttar Pradesh revealed a declining trend in North-Western India during 2016–2019, consistent with CREAMS data reporting 41% and 15% reductions in 2018 over 2016 and 2017, respectively. According to the Press Information Bureau (2019), in-situ burning decreased by 29.5%, 24.5%, and 11.0% in Haryana, Punjab, and UP, respectively, compared to 2017. However, a 45% surge in 2020, mainly in Punjab, coincided with farmer protests against new farm laws (DARE, 2022), indicating socio-political influences on burning practices. Still, the high percentages of paddy land subjected to burning in Punjab and the comparatively quicker expansion of burned land in Haryana highlight regional differences and are consistent with previous findings by Saxena et al. (2021) about state-specific difficulties with enforcement and farmer compliance. The findings from our regression analysis align with earlier research emphasizing the role of crop diversification in reducing environmental stress. As highlighted by Kumar et al. (2022), diversification into crops such as potatoes and basmati rice can mitigate the practice of residue burning our results support this evidence. At the same time, the strong positive relationship between groundwater irrigation and stubble burning points to the structural rigidity of the paddy–wheat system. This observation resonates with the concerns raised by Lan et al. (2022); Debangshi and Ghosh (2022) and Saha et al. (2022) regarding the interconnected pressures on water, air, and soil resources. Consistent with the findings of Huria et al. (2021), the results indicated that higher literacy levels were associated with an increase in stubble burning, a contrast to the common expectation that education would promote environmentally sustainable practices. Future research could contribute by adopting micro-level household surveys to better capture behavioral drivers, explore the economic feasibility of alternative crop choices, and assess the long-term adoption of residue management technologies such as the Happy Seeder under varying policy and market environments.

CONCLUSION

Trend statistics of the study have shown the decreasing trend of burning events for all three states from 2016 to 2021; however, when growth rates of paddy burnt area were compared vis-à-vis growth rate in area districts, viz., Haryana, like Palwal, Jind, Panchkula, Sonapat and Panipat and the districts of WUP like Amroha, Badaun and Baghpat, exhibited increasing trends. Panel regression highlights a positive effect of paddy cultivation, increased groundwater availability, and higher literacy rates on stubble burning. This underscores the need for targeted awareness and education programs directed toward literate populations. To address the challenges effectively, implementing stricter regulations on stubble burning, incentivizing farmers in high-frequency burning districts to transition

towards high-income vegetable crops (diversification) are evident. Furthermore, as per evidence supported by primary data of the current study and literature, the technological practices, viz., Happy Seeder, to be promoted through mass media channels during the paddy-wheat cultivation window period.

DECLARATIONS

Ethics approval and informed consent: Ethical approval was not required as the data was taken from published sources and public domain.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The authors declare that during the preparation of this work, thoroughly reviewed, revised, and edited the content as needed. The authors take full responsibility for the final content of this publication.

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